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Highly Linear and Transparent 3-18 GHz Optical Microwave Link

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Abstract

A highly linear optical microwave link transmitter based on heterodyne phase-locked DFB lasers is presented. The transmitter is transparent for FM and PM input signals with carrier frequencies ranging from 3-18 GHz. Distortion-free transmission of a 7.6 GHz FM PAL video signal over 25 km of optical fibre is demonstrated.

Introduction

New types of microwave systems, that require long distance (m-20 km) cable based transmission or extensive signal distribution, are now emerging. Examples are: distributed microwave systems for cellular phone networks [1], feeding of remote antennas, phased array antennas and delay lines.

Standard microwave transmission techniques become increasingly difficult or even impossible to use in such systems because of high losses. In this case optical microwave links may be the only feasibl̶e solution. It is, however, of great importance, that the optical link is capable of transmitting the microwave signals without adding significant distortion. This requirement proves quite difficult to fulfill using conventional optical schemes, especially at high carrier frequencies (>10 GHz), due to the non-linear modulation properties of semiconductor lasers and optical modulators.

Here we present an intrinsically linear optical link based on a novel transmitter scheme using heterodyne phase-locked DFB lasers. This transmitter can presently be operated at carrier frequencies ranging from 3-18 GHz [2] and it has the potential of monolithic opto-electronic integration. The carrier frequency range for the transmitter is only limited by the bandwidth of the

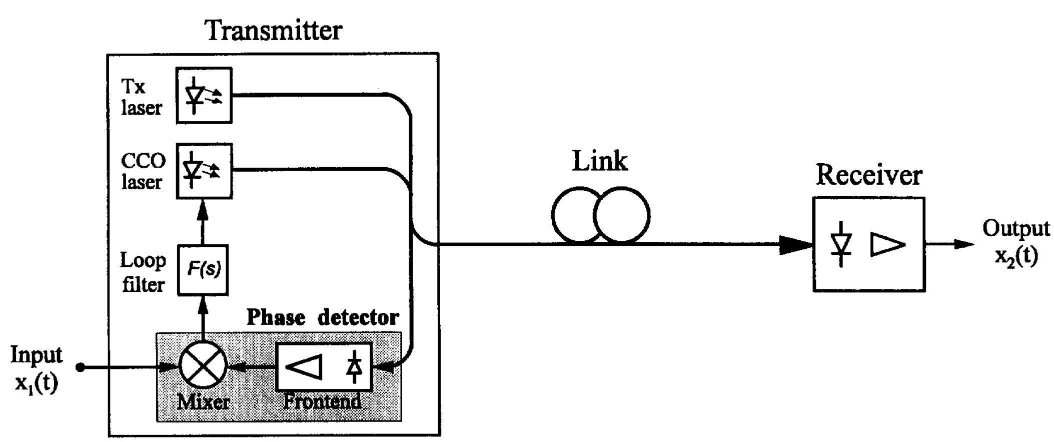

Figure. 1: Linear optical microwave link.

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phase detector electronics and could be extended to the 100 GHz range with todays state-of-the-art MMIC processes.

Concept

The link transmitter, as shown in Fig. 1, consists of a free running transmitter laser (Tx-laser), an opto-electronic phase detector, a loop filter and a Current Controlled Oscillator laser (CCO-laser). The microwave signal generated by the beat of the two semiconductor laser signals is compared to the microwave input signal, $x_1(t)$, which may be any angle modulated (analog/digital - PM or FM) signal. The resulting phase error signal is fed back to the CCO-laser which is forced to track the Tx-laser with a frequency and phase offset equal to that of $x_1(t)$.

Loop filter	Passive 2. order
Loop gain at 1 Hz	1.1 GHz
Loop bandwidt	170 MHz
Damping coefficient	0.8
Natural frequency	105 MHz
Propagation delay	400 ps
Lock range	170 MHz
Acquisition range	630 MHz
Phase variance	0.04 rad^2

Table. 1: Parameters of the OPLL

The optical phase locked loop (OPLL) simultaneously reduces the phase noise from the beat between the two laser signals and directly transfers the input signal, $x_1(t)$, to the optically transmitted signal, $x_2(t)$

The wide bandwidth of the OPLL, for which loop data are listed in Table. 1, allows linear transmission of signals with high spectral widths. This has been verified experimentally for a sinusoidal FM input signal by comparing the FM-index of the received signal, $x_2(t)$, with that of the input signal, $x_1(t)$.

Ideally, the ratio between these two indexes equals the closed loop transfer function of the OPLL [3]. As shown in Fig. 2, fine agreement is obtained between measurements and calculations based on the loop parameters in Table. 1. Both calculations and measurements show, that the OPLL transmitter can be used in a highly linear FM link for modulation frequencies of up to around 50 MHz with a FM-index deviation of less than 1.5 dB.

In addition to high linearity, the phase variance (phase noise) of the received signal, $x_2(t)$, must be low. The total phase variance consists of a contribution from laser phase noise and a contribution due to the modulation of the input signal. The phase variance attributed to semiconductor laser phase noise is as low as 0.04 rad^2 ensured by the wide bandwidth of the OPLL [2]. The modulation induced phase variance

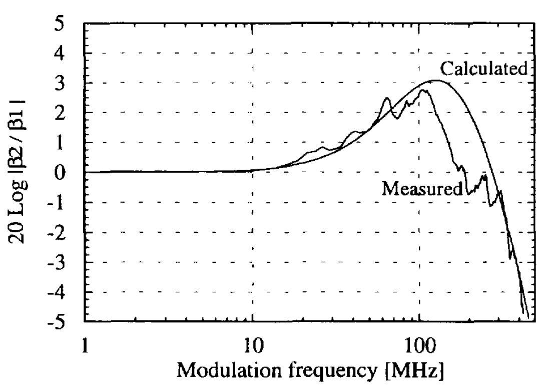

Figure 2: Measured and calculated ratio between FM-index of transmitted and input signal.

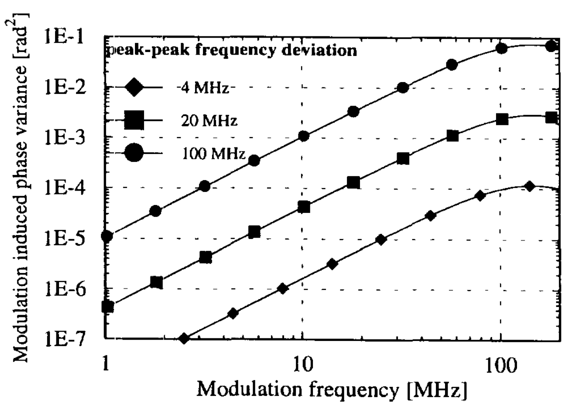

Figure 4: Calculated modulation induced phase variance.

calculated from the OPLL parameters is shown in Fig. 3. As seen, this optical link is capable of transmitting signals with a spectral width of around 100 MHz without adding significant phase noise to the signal compared to the 0.04 rad^2.

Link Experiment

To demonstrate the concept, the OPLL transmitter has been used in an optical microwave link for transmission of a standard radio-link FM PAL video signal, c.f. Fig. 4. The FM video signal occupies a spectral width of up to 30 MHz DSB and is transmitted over a distance of 25 km of optical fibre. The received signal has been analyzed with a video measurement set. Negligible signal degradation is observed for the signal transmitted on the optical link compared to a back-to-back measurement of the microwave link except for the transmission loss. As an example, the colour states of the video signal are recovered perfectly in both magnitude and phase as shown in Fig. 4.

The FM link·experiment has also been used for a detailed evaluation of the intermodulation performance of the optical microwave link. The intermodulation performance is traditionally measured in terms of baseband-to-baseband differential gain and differential phase [4]. These include all contributions from amplitude response, group delay response, and AM/PM conversion of the link. The differential gain and differential phase for the optical link is ±1.5% and ±0.3^o compared to ±1.4% and ±0.1^o for the electrical back-to-back measurement. For comparison, the requirements in a main FM TV-link are ±4% and ±2^o [5].

Finally, the weighed S/N ratio for the FM video signal transmitted over a distance of 25 km of optical fibre is as high as 58 dB. This is only 2 dB less than required for a main FM TV-link [5] and could easily be increased using lasers with a slightly lower phase noise thereby decreasing the intrinsic phase variance of 0.04 rad^2.

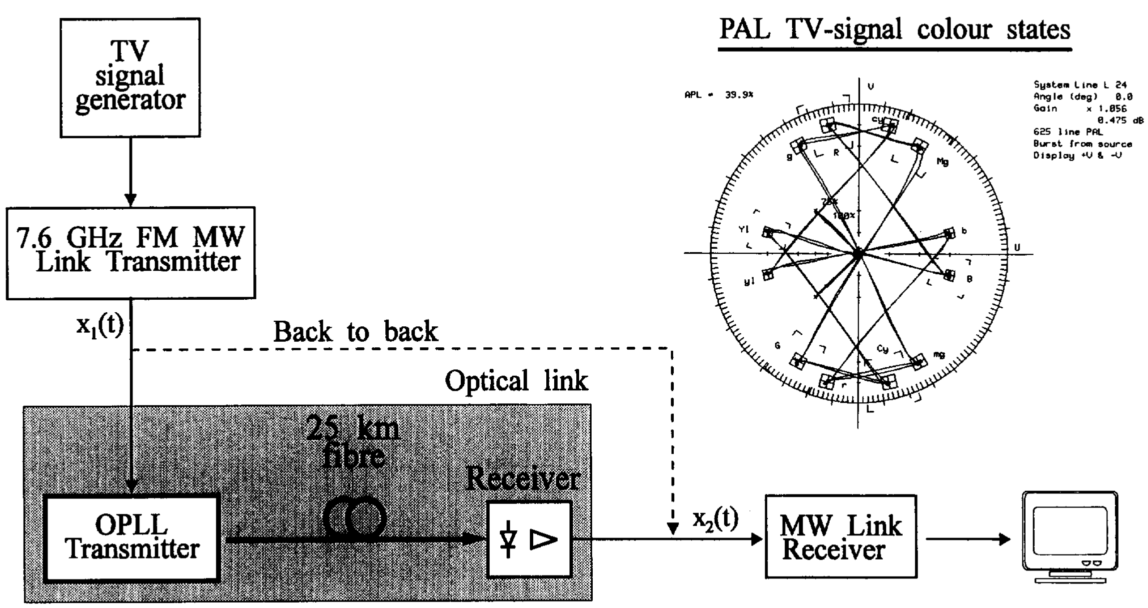

Figure 4: 7.6 GHz optical microwave FM link experiment setup. The standard MW link transmitter and receiver are directly connected for the back-to-back measurements.

Conclusion

In summary we have presented a highly linear optical microwave link transmitter based on heterodyne phase-locked semiconductor DFB lasers. The link transmitter can presently be used for carrier frequencies between 3-18 GHz and is transparent for angle modulated signals (analog/digital - FM or PM) with modulation frequencies of up to 50 MHz. The link transmitter has been characterized based on standard measurements used for PAL FM video signals and demonstrates that the optical links fulfills the requirements of standard microwave links.

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